RecyMblock - application of recycled mixed aggregates in the manufacture of concrete construction blocks.

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Summary

This paper discusses the potential use of mixed construction and demolition waste (mCDW) in concrete blocks for masonry work as aggregate's replacement for virgin aggregates. The conclusion is that it is possible to produce concrete blocks with a high percentage of recycled mixed construction and demolition waste. The replacement percentage with recycled aggregates was 75 wt% for hollow blocks and 95 wt% for full ones. The production of this type of concrete block, called 'RecyMblock', having similar properties as the ordinary concrete blocks made with virgin aggregates, is aimed to achieve a waste-to-product approach, thus contributing to close the loop of material use. As a way of dissemination to the public, 3500 hollow 'RecyMblocks' were used as an example in the renovation of the Centre of Sustainable Building in Heusden-Zolder (BE).

Keywords: Construction and demolition waste, Recycled aggregates, Concrete blocks, Mix proportioning, Compressive strength

1. Introduction

With an annual production of 10 million tonnes, construction and demolition waste is one of the most important waste streams in Flanders, Belgium. 95% of this construction and demolition waste (CD&W) is processed into recycled aggregates. The amount of recycled concrete aggregates and the amount of mixed aggregates are about the same. In Flanders, Belgium there is a well developed recycling industry for CD&W, with more than 165 recycling companies on fixed locations and 44 certified mobile installations, most of which are SMEs. [1]

Recycled aggregates have evaluated towards a worthy alternative for natural aggregates. Their use should be looked at from a point of chain management and economic use of natural mineral. Therefore more applications with added value should be found for these kind of recycled aggregates that usually end up in low grade applications. This is the case for mixed recycled aggregates.

Currently, a series of research projects are up and running in order to optimize processing and recycling construction and demolition waste streams [2][3][4][5][6]. These more technologically oriented research projects aim to look for the use of recycled aggregates and focus on the value chain of C&D Waste by closing the loop. Other research performed at the Belgian Building Research Institute BBRI involves a rethinking of all steps which lead to waste.

Whilst a lot of research is done on using recycled concrete aggregates, less research is performed to find high grade applications for the use of mixed recycled aggregates. This paper shows that it is possible to produce an industrial competitive product. Mixed recycled aggregates (MRA) were used as a replacement of natural aggregates in the production of hollow and full concrete blocks.

The aim of this research was to produce construction blocks with a high level of MRA with a quality similar to the standard products on the market. Up to 95 wt% MRA was used in the production of full concrete construction blocks and up to 75 wt% in hollow ones.

The research program focussed on transfer of technology towards the industry and the market. First of all an inventory was made of all relevant knowledge concerning processing CD&W and the state of the art in the industry concerning building brick production. Mixed aggregates were quantified and classified. Secondly, mixtures for the production of full and hollow blocks were designed, laboratory testing has been done and full-test-production was set up. This was an iterative step with small adaptations that led to improvement of the designed mixture. Properties like compressive strength, density, frost-thaw resistance, etc. were performed. Finally, 3500 hollow building bricks were produces in an existing building block manufacturing company. These blocks were used as an example in the “Centrum Duurzaam Bouwen“ (Centre of Sustainable Building) in Heusden-Zolder. This was to prove the high added value of MRA in the production of building blocks.

The conclusion of the research was that it is possible to produce building blocks with a high percentage of mixed recycled aggregates replacing natural aggregates. These building blocks were comparable to the standard building blocks. The compressive strength was more than 10 MPa with a density of between 1600 and 1900 kg/m³. Although the water absorption rate was more than 8 %, these blocks were not affected by 14 cycles of frost-thaw testing.

2. Using recycled aggregates

Concrete blocks are primarily used as building material in the construction of walls. Concrete blocks are one of several precast concrete products used in construction. The term precast refers to the fact that the blocks are formed and hardened before they are brought to the construction site. Concrete blocks can have one or more hollow cavities, and their sides may be cast smooth or with a design. For use in foundations masonry work concrete blocks without cavities are used. In use, concrete blocks are stacked one at a time and held together with fresh cement mortar to form the desired length and height of the wall.

Secondary aggregates get more and more used as a substitute for gravel. This is because there is a need to reduce the amount of waste which is produced annually and because it is necessary to use natural resources sparingly. The current Flemish law “VLAREA – Vlaams Reglement Inzake Afvalvoorkomingen –Beheer” [7], which focuses on preserving the environment, allows the reuse of certain waste streams into specific uses, including constructional applications.

In all developing and industrial countries, large amounts of industrial waste or by-products accumulate every year. The recycling of these materials is of increasing interest worldwide, due to the high environmental impact of the cement and concrete industries [8][9]. Also, for the production of concrete, a high amount of aggregates is needed. Nearly all natural aggregate comes from excavation of riverbeds or quarries, leaving the open space with deep holes and disturbing the ecosystems.

Poon et al. [10][11] have shown that it was feasible to produce paving blocks prepared with 25% crushed clay brick. He used concrete mixtures which differ substantially from these described in this paper. The mix proportions that were used for the paving blocks contained also more cement (670 kg/m³) with W/C-ratio’s up to 0,49. The concrete mixtures described in this work are made with 180 kg/m³ cement (OPC). The amount of water is about 10% of the cumulated mass of all other ingredients: cement, sand and aggregates.

Pimienta et al. [12] investigated the use of recycled aggregate used for making buiding blocks. It’s not clear whether they used recycled concrete aggregates of mixed recycled aggregates. There are however substantial differences between the research of Pimienta and the research of Boehme. Pimienta used about 26 wt% recycled aggregate 6/12 and 125 to 145 kg/m³ cement for producting of hollow blocks. The mean value of the compressive strength at 21 days was 5.52 MPa to 7,50 MPa. Boehme used 75 wt% mixed recycled aggregate 0/7 (0/2 & 2/7) and 180 kg/m³ cement. The mean value for the compressive strength at 28 days was 10.3 MPa.

Harmful effects of concrete on the environment can be reduced by producing durable concrete with effective use of resources. Industrial by-products and solid wastes can be used for this purpose. According to industrial ecology concept for sustainable development, by-product of one industry may be a raw material for another one. Therefore, detrimental effects of both industries to the environment can be reduced [8][9]. For this reason, cost, durability and environmental friendliness are at a starting point of being used as important criteria in developing concrete technologies [13].
In case of usage of these by-products and solid wastes in concrete as aggregate's replacement, each of them would be a raw material having economical value. Therefore, not or low valuable solid wastes will become valuable alternative to virgin aggregates. This waste-to-product approach will cast a light on new usage fields for industrial by-products.

Like in all new applications made with waste-products, chemical and physical environmental effects may cause deterioration of the end-product resulting in damage to the product or to the construction were it is applied in. To investigate concrete quality, durability, and deterioration, mechanical, chemical and other tests are available. Therefore, concrete elements containing industrial by-products or solid wastes as aggregate's replacement should at least be investigated with regards to degradation causes and mechanical properties.

3. Production of concrete blocks

The concrete commonly used to make concrete blocks is a mixture of cement, water, sand and gravel. This produces a gray block with a fine surface texture and a high compressive strength. A typical concrete block weighs 10 to 16 kg. In general, the concrete mixture used for blocks has a higher percentage of sand and a lower percentage of gravel and water than the concrete mixtures used for general construction purposes. This produces a very dry, stiff mixture that holds its shape when it is removed from the block mold. In addition to the basic components, the concrete mixture used to make blocks may also contain various chemicals, called admixtures, to alter curing time, increase compressive strength, or improve workability.

The production of concrete blocks consists of four basic processes: mixing, molding, curing, and cubing. The following steps are commonly used to manufacture concrete blocks.

3.1 Batching and mixing

Fig.1 "RecyMblock" in production

Sand, gravel and cement are transported to the concrete plant by truck. Certain materials, such as inert aggregates, are typically stored outdoors in stockpiles. Moisture-sensitive materials, such as cement and fly-ash, may be stored in high-capacity silos. As the materials are needed, they are transported by conveyor to large storage bins at the top of the block plant. At the start of production, the raw materials are discharged into a weigh batcher, which measures the correct proportion of dry materials for the mix. The dry materials are mixed thoroughly before adding water and admixtures. The proportioning of the mix is carefully controlled by computer. Most concrete blocks are produced using zero-slump concrete, which requires a minimal but very precise amount of water.

3.2 Molding and curing

After mixing is complete, the batch is discharged into the hopper of the compacting machine. In a modern block making plant, blocks are produced on wooden or steel boards. The boards are empty when entering the compacting machine. First, the empty board is placed under the mold. Then, a filling box comes on the top of the mold and fills it from above taking care of an even distribution of the concrete. Next, the concrete is compacted in the mold by use of a tamper head and vibration. Finally, the mold is lifted, leaving the freshly formed block on the board. The filled board is then pushed out of the compacting machine onto a conveyor belt (Figure 1). As the block travels down the belt, a rotating brush removes loose particles of aggregate from the top surface of the block. At this stage of the process, the uncured blocks are referred as "green" blocks. Afterwards the "green" blocks are placed into a curing chamber at normal temperature for at least 24 hours in order to harden and achieve the required mechanical properties.

3.3 Storage and transport

Boards of cured blocks are removed from the curing chamber and transported by the automated forklift to a stacking unit. Stacked blocks are then moved to an outdoor storage yard. Large quantities of blocks are stored until declared ready for transport to the construction site.

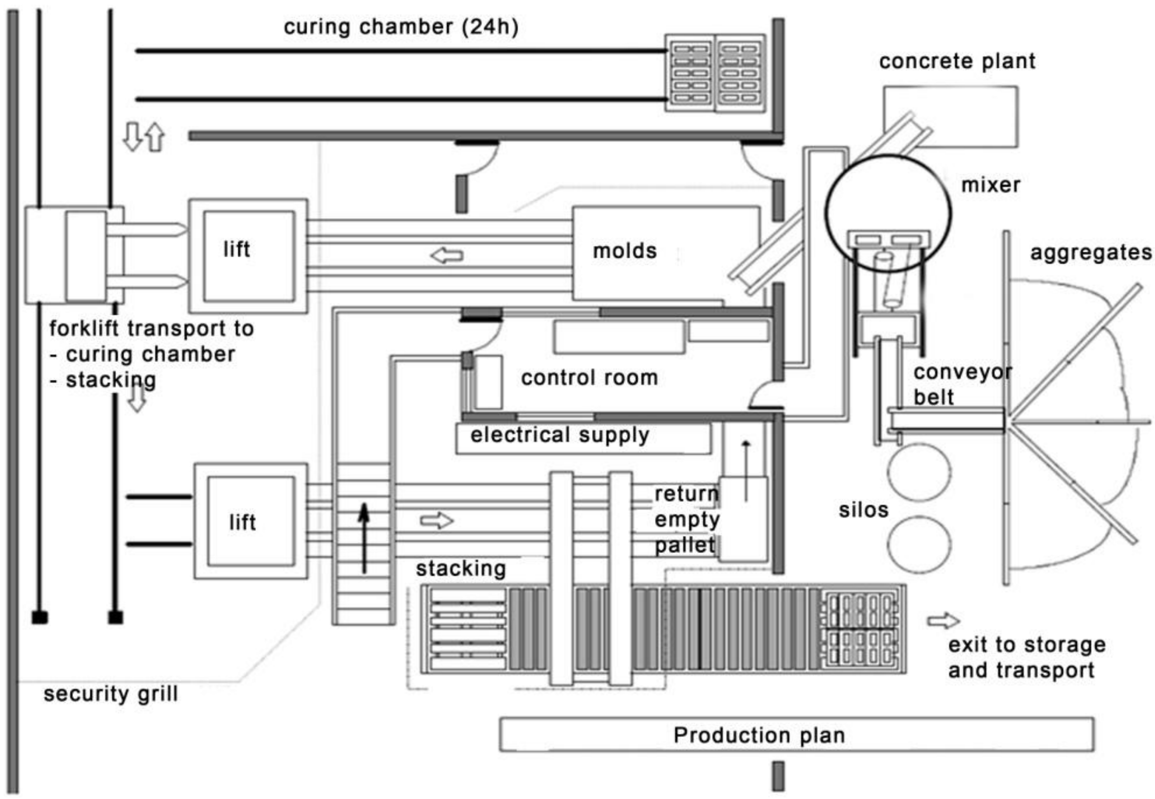

Fig. 2 Production plant of concrete block making

3.4 Quality Control during production

The manufacture of concrete blocks requires constant monitoring to produce blocks that have the required properties. The raw materials are weighed electronically before they are placed in the mixer. The trapped water content in the sand and gravel may be measured with ultrasonic or microwave sensors, and the amount of water to be added to the mix is automatically adjusted to compensate. At the end of the mixing cycle, the exact moisture level is controlled in order to avoid a mixture being too wet or too dry. As the blocks emerge from the block machine, their height may be checked with laser beam sensors or other devices.

4. Mix proportioning

4.1 Classic raw materials

4.1.1 Cement

Although it is possible to produce concrete blocks with almost every type of cement, there are some factors to be taken into account. After 24 to 48 hours curing, the blocks leave the curing chamber and have to be stacked ready for transportation. At that moment, the blocks need to be strong enough so that they are not damaged during stacking. Therefore rapid hardening cement with high early strength (CEM I-type cement) is useful.
When putting into place, the masonry block has to be resistant to certain chemicals (sulfates, chlorides, …) or to efflorescence by white deposits of water-soluble salts. Another consideration is the risk of damages caused by alkali-silica-reaction (ASR). Preventing ASR will provide a lasting stability of the block. The use of cement blended with blast furnace slag will reduce the risk of these damages. These considerations lead to the use of CEM III – type cements.

4.1.2 Sand

Sand that can be used for producing concrete blocks mainly comes from three sources:

1. Riverbeds, having typically round grains. Upstream this sand contains little or no fines (maximum diameter up to 5 mm), while downstream sand becomes finer (1 mm or less).
2. The sea, having rather edged sand. This sand is as fine as downstream river sand.
3. Sand from quarries: this sand might be a by-product from the exploitation of limestone or might be sand found in the underground. These sands are rather fine and usually contain a lot of fines.

Usually, 2 types of sand are mixed. The influence on the workability of the fresh concrete mix, the influence on the final strength, and the texture of the block, will determine the quantity of sand to be used in the mix.

4.1.3 Mixed Recycled Aggregates

Table 1 Mixed recycled aggregates

	Recycling plant		
Composition	**1**	**2**	**3**
concrete [%]	63.1	56.1	61.5
red brick [%]	20.1	25.5	18.8
cement stone [%]	16.4	17.8	19.2
other [%]	0.4	0.6	0.5
Mean Values			
real density [kg/m³]	1824	1878	1875
apparent density [kg/m³]	1308	1331	1426
methylene blue [cm³/g]	0.24	0.57	0.39
sand equivalent [%]	79	72	68
Micro Deval value [%]	35	42	42
Los Angeles abrasion [%]	35	41.5	41.7
chlorine -ions [%]	1.21 E-4	0.53 E-4	0.48 E-4
water soluble sulphates [%]	0.039	0.042	0.033

The aggregates that were used to produce the ‘recyMblocks’ were mixed recycled aggregates (MRA) derived from construction and demolition waste which was processed in a recycling plant. The main properties of the MRA are show in table 1.

4.1.4 Other aggregates

Probably excluding a number of alternative production sites, aggregates used for concrete come from the same sources as sand does. The main difference is the particle size. Where the biggest sand grains are about 2 mm, 2 mm is about the size of the smallest particle in aggregates. For the production of concrete blocks, aggregates up to 8mm or sometimes 16 mm are considered.

The most economical source of the materials used in block production is determined by its cost and the cost for transportation to the block making factory.

4.2 Mix design

Composing the right mix for block production is a very complex balance between visual result, block quality and the cost of the raw materials. An example of mix formulas for different types of blocks is shown in table 2. Table 3 and figure 2 show the particle size distribution of the designed mixture for the production of “RecyMblocks”.

4.3 Preliminary tests

Before making a full scale test in production, some preliminary tests were performed. This was necessary because for this type of concrete mixture there isn’t any design methods available compared with the mix design of fresh (rich) concrete. The kind of concrete mixture that is used to produce concrete blocks is a very dry one with a low dosage of cement. In order to perform preliminary tests to check if the mixture would be valid for large scale production, a mini block forming machine was made in the laboratory. This machine consisted mainly of a wooden board upon which a mold for one block was attached and this was placed in a frame in such a manner that vibration was submitted to the wooden board.

Table 2 Mixing formulas for different types of blocks

Mixing Formulas for blocks			
Aggregates	Block for foundation masonry	**RecyMblock for masonry**	Block for industrial visual masonry
Sand 0/1 (quarry)	15%	**2%**	10%
Sand 0/2 (sea)	20%	**5%**	
Sand 0/2 (river)		**31%**	30%
Stone 2/4 (quarry)			50%
Stone 4/6.3 (quarry)			
Stone 2/6.3 (quarry)	50%		
Stone 6.3/14 (quarry)	15%		10%
MRA 0/7		**62%**	
Cement CEM I 52.5 N	145 kg/m3		
Cement CEM I 42.5 R		**180 kg/m³**	
Cement CEM III/A 52.5 N			180 kg/m³

Table 3 Particle size distribution Mix Design “RecyMblock”

	Partical size distribution Mix design 'RecyMblock'									
mesh [mm]	0.08	0.125	0.25	0.5	1	2	4	6.3	7.1	10
sand mix	0.31	1.14	21.64	48.59	78.16	89.33	97.70	99.99	100.00	100.00
MRA	2.60	5.40	9.77	11.43	12.61	14.81	31.82	64.05	75.43	95.48
least square result	18.05	20.06	24.23	30.12	38.46	50.25	66.92	81.44	85.84	100.00
mix proportioning	11.66	13.50	22.98	33.17	43.99	49.05	61.37	80.05	86.36	97.49

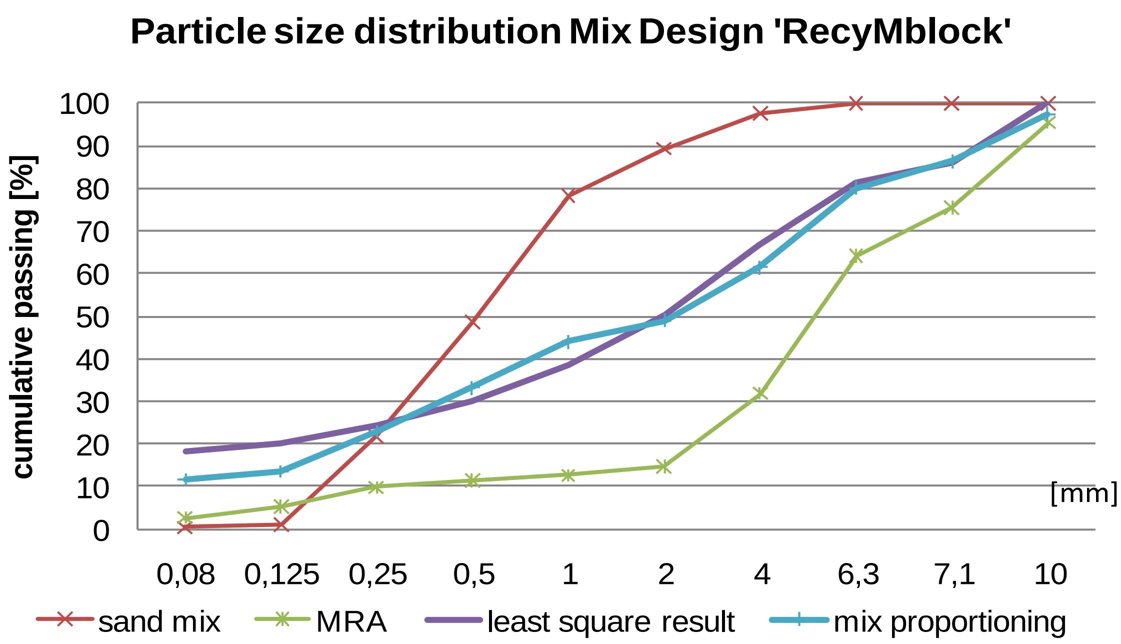

Fig. 3 Particle size distribution of mix design "RecyMblock"

The mold was filled with a concrete mixture and a tamper was put on top so that a small pressure was applied. After vibration of 15 seconds, the pressure on top was released without removing the tamper. Next, the mold was removed together with the tamper. The fresh concrete block was then removed from the board and put into a climatic chamber to cure. This way many blocks were made and they were tested on 3, 7, 14, 21 and 28 days.

For manufacturing concrete blocks in a production plant, the performance of the concrete mixture (handling in the block forming machine) and the demolding ability are of great importance. The water content of the concrete mixture is adjusted based on these criteria. Based on the results of the preliminary tests, the most suitable mixes for manufacturing were determined. Based on the results of the preliminary tests, a series of full concrete blocks were manufactured in the production plant. The main results of these test-blocks made in a full scale test-production are set out in table 4.

4.4 Full scale tests

Table 4 Results of tests on full blocks

Number of Days	Density [kg/m³]	Length [mm]	Height [mm]	Widt h [mm]	Compressive strength f_{bk} [MPa]
3	1680	285.8	138.9	187.3	6.7
7	1671	285.5	138.6	188.3	7.4
14	1728	285.6	138.8	188.2	8.5
21	1651	286.1	138.5	187.4	9.5
28	1675	285.9	138.6	187.3	9.6

After the first full scale test-production was successful, more full blocks were produced and other properties, such as water absorption, frost and thaw resistance, density, sizes, were determined.

Based on the results of the full blocks, a new mixture was investigated for the production of hollow concrete blocks. Since the demolding ability of hollow blocks is slightly different from the demolding ability of full block, the original mix design had to be altered. The amount of recycled aggregates used in the mix had to be lowered due to the fact that the recycled aggregates, which contained about 40% masonry brick, are porous and they tend to make the mixture sticky while for the production the opposite was wanted in relationship to the demolding.

4.5 Results and discussion

The main results of the various properties are given in table 5. The discussion in the following section is based on test results obtained on full RecyMblocks and hollow RecyMblocks.

The apparent dry density of the blocks with recycled aggregates (1680 kg/m³ for full blocks; 1270 kg/m³ for hollow blocks) appears to be slightly less than of ordinary blocks (2100 kg/m³ for full blocks; 1350 kg/m³ for hollow blocks). The reason for this lower density is certainly due to the fact that the density of the recycled aggregates is lower than the virgin aggregates in the ordinary blocks. The lower mass of the "RecyMblock" is an advantage on the construction site. For the labourer the handling of these blocks will be less tiring physically. Also for transportation, the lower mass is an advantage.

The surface of the 'RecyMblock' is even but not as smooth as ordinary concrete blocks. The colour is gray with a brownish tone. The dimensional variations are less than the threshold in the standard NBN B 24-207. Therefore these blocks comply with this standard.

The compressive strength of the 'RecyMblock' is determined according to the standards NBN B 24-201 and NBN B24-301. According to the standard NBN B 21-001 (EN 771-3) the classification of 'RecyMblock' in the full block version is quality class 10/1.9 and in the hollow block version quality class 8/1.6.

Table 5 Results

Type of block	Ingredients [kg/m³]	Compressive strength [MPa] NBN B 24 - 201 & 301	Density [kg/m³] NBN B 24-206	Designation f / ρ NBN B 21-001 (EN 771-3)	Capillarity [%] NBN B 15-215	Frost and Thaw test NBN B 15-231
Full	MRA 0/2 : 450 MRA 2/7: 1100 Sand : 0 CEM I 42.5 R: 180 Moisture: 14.26 %	14.5	1680	10 / 1.9	12.96%	No damage after 14 cycles
Hollow (29% cavities)	MRA 0/2 : 200 MRA 2/7: 1100 Sand 0/2: 300 CEM I 42.5 R: 180 Moisture: 11.96 %	8.9	1270	8 / 1.6	11.30%	No damage after 14 cycles

The water absorption by capillarity (NBN B 15-215) for this kind of concrete blocks made with recycled aggregates is higher than the threshold of 8%. Measured values of capillarity tests are between 11.5% and 13%. If the blocks were to be used as facing blocks, then this would be an important problem. The 'RecyMblock' was not designed to be used in facing masonry, therefore the high value the capillarity doesn't form a problem. However, water absorption of more than 8% could lead to damage due to frost and thaw. Frost and thaw tests were conducted (NBN B 15-231) on both types of concrete blocks with recycled aggregates. After 14 cycles no damage was observed. This is probably because the size of the pores in the recycled aggregates is large enough to let the frozen water crystals expand during the frost and thaw cycles, and so the build up pressure in the pores is not as high that it demolishes the aggregates.

The compressive strength of both versions of the 'RecyMblock' is in the same range as other ordinary concrete blocks on the market. This shows that the 'RecyMblock' has potential to be used on the construction side. The overall goal of this research programme was to investigate the possible use of a high amount of mixed recycled aggregates in the manufacture of full and hollow concrete blocks. The aim for these blocks was set at indoor use, not in continuous contact with water and not susceptible to frost and thaw.

5. Conclusion

Test results show that it is possible to produce concrete blocks with a high amount of mixed recycled aggregates. Although during the research programme it was possible to replace 100% of the original natural aggregates by recycled aggregates, it was sometimes necessary to reduce the recycling rate to 95%. Some sand had to be added to make the mixture lean. This depends on the quality of the recycled aggregate (less or more recycled red brick, less or more fines) and its relationship to the demolding ability of the freshly compacted block.

In general a recycling rate of 95 wt% in the production of full "RecyMblock" was achieved. For hollow "RecyMblock" the recycling rate was 75 wt%.

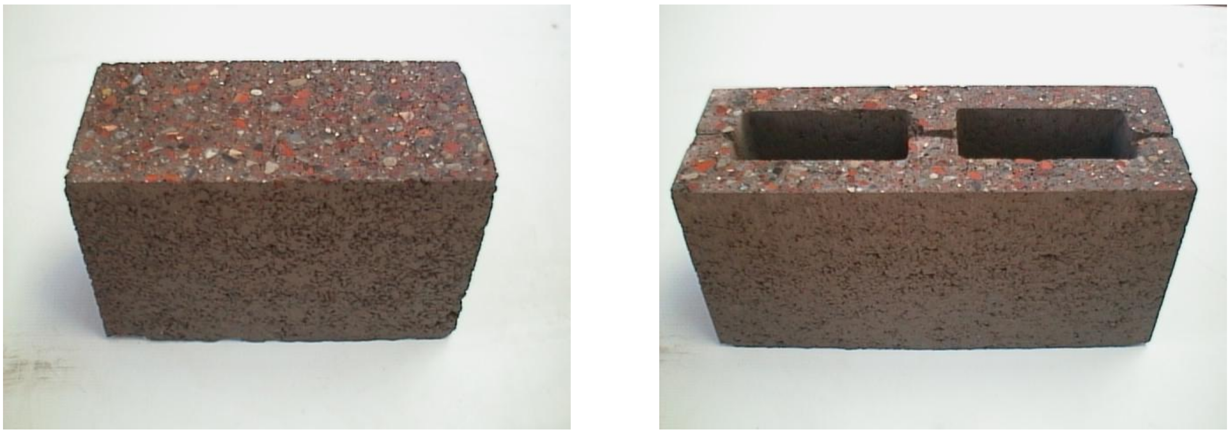

Fig. 4 Full and hollow "RecyMblock"

Fig.5 "RecyMblock" in use

The characteristics of the "RecyMblock" show that this type of concrete block can be used for indoor masonry applications. Although no damage was detected after 14 cycles of frost and thaw testing, it is not advised to use this concrete block for facing masonry or outside work in continuous contact with water.
By means of example 3500 hollow "RecyMblocks" were produced and used in the renovation works of the Centre of Sustainable Building (Centrum Duurzaam Bouwen) in Heusden-Zolden, in the province Limburg (Figure 5). This was to show the possibilities of the "RecyMblock". In its way, the "RecyMblock" is an example of a waste-to-

product approach in dealing with construction and demolition waste and of chain management of raw materials for concrete block production.
At the time of the research programme, the prices of high-speed red building brick were historically very low. Concrete blocks for general masonry work could not compete. Even though the "RecyMblock" was cheaper in production, due to the fact that recycled aggregates are cheaper, it still could not compete with the high-speed building brick. Nowadays, the price difference between both kinds of building materials is much smaller, so the time has come to look into the production of the "RecyMblock" again.

Further research to fine tune the production of blocks with high amounts of recycled aggregates is needed. It would be worthwhile to look into some other issues concerning the variety of recycled aggregates and the presence of certain impurities which may be present in recycled aggregates. Further research could help to determine the thresholds up to where recycled aggregates can be used to produce concrete blocks that comply with the standards and the intended purpose.

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